

## §12. Helium Retention Properties under Long Pulse Discharges in LHD

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Controls of particle balance and impurity generation from the wall are the key issues for establishment of a fusion reactor. The Large helical device (LHD) has an important advantage for steady state operation (SSO). First wall panels and divertor plates of LHD are stainless steel (SUS316L) and graphite, respectively. The former is the major material in LHD, and the graphite area is only about 5% of the total plasma facing area. The temperature of the first wall is almost kept at room temperature (R.T.) during plasma discharges. In the recent SSO experiment, a high-performance ultra-long pulse helium discharge of 48 min with  $n_e \sim 1.2 \times 10^{19} \text{ m}^{-3}$ ,  $T_{ie} \sim 2 \text{ keV}$  was successfully achieved by the higher heating power of 1.2 MW. However, such ultra-long pulse helium discharges had been disturbed by two major issues that are closely related with plasma wall interactions (PWI). The first issue is the dynamic change of the wall pumping rate during discharges. The second issue is the termination of the discharge by sudden mixing of C and Fe impurities with intensive sparks. This report was focused on the first issue.

In the case of the 48 min discharge, though the pumping speed was almost constant during the entire discharge period, the fueling rate of helium had to be changed dynamically by using a feedback fueling system for maintaining the static electron density ( $n_e \sim 1.2 \times 10^{19} \text{ m}^{-3}$ ). This means that the wall pumping rate could have been dynamically changed as time passed. From an analysis of a global particle balance model, the specific wall pumping rate ( $\Gamma_{\text{wall}}$ ) can be separated into three phases: phase 1 (0-300 s), phase 2 (400-1500 s), and phase 3 (2000-2800 s). The wall pumping rate of phases 1, 2, and 3 were  $\sim 1.0 \times 10^{20} \text{ He/s}$ ,  $\sim 3.5 \times 10^{18} \text{ He/s}$ , and  $\sim 1.4 \times 10^{19} \text{ He/s}$ , respectively. This dynamic change of the  $\Gamma_{\text{wall}}$  disturbs the stable particle control. This phenomenon is caused by the microscopic modifications of the wall surface. The retention property of the helium on the first-wall surface during the long pulse discharge was investigated by using the retractable material probe experiment. There then was discussion regarding a key factor of the controlling of the continuous wall pumping capability of helium.

Bulk SUS316L plates of  $10 \times 10 \times 0.1 \text{ mm}^3$  and pre-thinned vacuum annealed SUS316L disks of  $3 \text{ mm } \phi$  were mounted on the probe head, and then were inserted into the first-wall equivalent position by using the retractable material probe system which is equipped with the LHD. Three sets of the specimens were prepared, and then were exposed to the three different exposure times of 1000 s, 3389 s, and 9980 s in total (the integrated time of several discharges) with the parameter of  $n_e \sim 1.2 \times 10^{19} \text{ m}^{-3}$ ,  $T_{ie} \sim 2 \text{ keV}$ . After the exposure, microscopic modification of the specimens was observed by means of transmission electron microscope

(TEM), and, also, retained helium atoms were quantitatively analyzed by using thermal desorption spectroscopy (TDS).

From the result of the TEM observation, very fine amorphous-like mixed-material deposition layer with the thickness of about 5 nm, 15 nm, and 40 nm were formed on the surface of the SUS316L specimen after exposed for 1000 s, 3380 s, and 9980 s, respectively. Their structures were very fine amorphous-like structures with porous features. Such kind of structures might act as the trapping site of helium during the long pulse discharges. In addition, TDS results indicates that the desorption peak of the three exposure cases were able to be divide two temperature region of a low-temperature region (300-600 K) and a high-temperature region (1000-1400 K). It was noted that desorption rate of helium was dramatically increased by increasing the exposure time. In a low-temperature region, it was included the desorbed helium from two kinds of trapping site of mixed-material deposition layer and weak trapping site of inside of the SUS316L matrix. The former trapping site could be a majority, because the thickness of the deposition layer was lineally increased by increasing the thickness of the deposition layer. Therefore, the amount of the desorbed helium at 300-600 K and thickness of the deposition layer were plotted as a function of an exposure time in Fig. 1. It was clear that the amount of helium retained in the mixed-material deposition layer is linearly proportional to the thickness of the mixed-material deposition layers. Saturation of the helium retention does not show any sign even at 9980 s exposure time, and the average retention rate of helium is estimated to be  $\sim 1.7 \times 10^{16} \text{ He/m}^2\text{s}$ . The total amount of the average retention rate in the entire LHD first-wall surface area ( $\sim 730 \text{ m}^2$ ) can be calculated as  $\sim 1.7 \times 10^{16} \text{ He/m}^2\text{s} \times 730 \text{ m}^2 = \sim 1.2 \times 10^{19} \text{ He/s}$ . This value is sufficient to explain the wall pumping rate of phase 3 ( $\Gamma_{\text{wall}} \sim 1.4 \times 10^{19} \text{ He/s}$ ) of the long pulse discharge. However, the trapping energy of the helium in the mixed-material deposition layer is very weak and is easily released when the temperature of the first-wall increases even at less than 400 K. Therefore,  $\Gamma_{\text{wall}}$  could gradually change through one discharge period. Generally speaking, it might have been thought that helium is retained in a minute amount in a carbon material. However, these results indicate that as long as the mixed-material deposition layer is continuously formed, the wall pumping is maintained during long pulse discharges, and affects the dynamic change of the wall pumping rate.

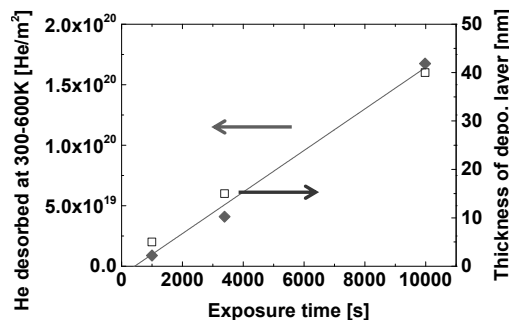


Fig. 1. The relationship between the thickness of the mixed-material deposition layer and the areal density of helium desorbed at 300-600 K as a function of an exposure time of the SUS316L specimens to the long pulse discharges